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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to an ultrasonic transducer and, more particularly, to an ultrasonic transducer well-suited for use underwater or for diagnosis of a living body.

2. Description of the Prior Art:

Ultrasonic transducers generally make use of a piezoelectric member which, as is well-known in the art, may be a ceramic piezoelectric member consisting of lead zirconate titanate, barium titanate, lead titanate or the like, a piezoelectric polymer member consisting of polyvinylidene fluoride or the like, or a composite piezoelectric member consisting of a polymer and a ceramic. The piezoelectric polymer member and the composite piezoelectric member have much higher workability and a lower acoustic impedance than the ceramic piezoelectric member and for this reason have come to be widely employed in ultrasonic transducers for use underwater or for diagnosis of a living body.

Fig. 2 illustrates an example of the cross-sectional structure of an ultrasonic transducer using a piezoelectric polymer member. The transducer includes a piezoelectric body 1 obtained by providing each of the opposing main surfaces of a flat, plate-shaped piezoelectric polymer member with an electrode, not shown. The piezoelectric body 1 has a reflector 2 deposited on one of its surfaces and is affixed to a support member 3 via the reflector 2. Numeral 5 denotes a specimen undergoing examination.

It is known that when an ultrasonic transducer of this construction is driven by a $\lambda/4$ driving waveform, namely when a $\lambda/4$ drive method is employed, sensitivity is maximized if the thickness of the piezoelectric body 1 is made $\lambda/4$. Note that λ_1 represents the sonic wavelength inside the piezoelectric body 1 at a frequency which is one half the free resonance frequency of the piezoelectric body 1.

Ordinarily, the thickness of the reflector 2 is set to $\lambda_2/4$ (where λ_2 is the sonic wavelength inside the reflector). However, it has been proposed in the specification of Japanese Patent Publication for Opposition No. 59-9000 to reduce the thickness of the reflector to below $\lambda/4$ in order to exploit the flexibility possessed by the piezoelectric polymer member and attain a higher efficiency and a wider band.

The graph of Fig. 3 shows the results of analyzing the sensitivity and response of an ultrasonic transducer when the thickness of the reflector 2 is varied from 0 to $\lambda_2/3$.

The analytic method is in line with the principle of analyzing, by a gradualistic method (or sequence definition equation method), the amplitude of a pressure wave produced under the application of a single voltage pulse, as set forth in the specification of Japanese Patent Application Laid-Open No. 60 185 499 (published 20.9.85). The thickness of the

reflector 2 is plotted along the horizontal axis, and both the sensitivity (relative values) and response of the ultrasonic transducer are plotted along the vertical axis. The characters S and R indicate the analytical data representative of sensitivity and response, respectively, and f stands for frequency (MHz). The various materials analyzed and the corresponding acoustic impedances are shown in Table 1. It will be understood from Fig. 3 that, for a reflector 2 having a thickness within the range $\lambda_2/30$ ($=4 \lambda_2/120$) to $11 \lambda_2/60$ ($=22 \lambda_2/120$) (A-A' line in Fig. 3), sensitivity and response are higher than for a reflector having a thickness of $\lambda_2/4$ ($=30 \lambda_2/120$). This agrees with the subject matter disclosed in the aforementioned specification of Japanese Patent Publication No. 59 9000 (EP-A 1 14 693).

The present invention, however, is directed to an ultrasonic transducer of the type shown in Fig. 1, which is formed from a polymeric or composite piezoelectric member, the surface of the piezoelectric body 1, namely the surface that receives the ultrasonic wave, has an acoustic matching layer 4 deposited thereon to serve as a protective layer for protecting the piezoelectric member and the electrode formed on the abovementioned surface. This ultrasonic transducer ordinarily is used by being brought into contact with the specimen 5 through the intermediary of the acoustic matching layer 4.

However, the ultrasonic transducer described in the abovementioned JP-B2-59-9000 does not possess an acoustic matching layer and the specification does not go beyond a description of the polymeric piezoelectric body. In general, the thickness and acoustic impedance of the acoustic matching layer are important factors which influence various characteristics of the ultrasonic transducer. Common technical knowledge in the prior art is that $\lambda_3/4$ is the preferred acoustic matching layer thickness (where $\lambda_3/4$ is the sonic wavelength inside the acoustic matching layer). However, whether $\lambda_3/4$ is indeed the optimum thickness of the acoustic matching layer has not been investigated, and neither has the relationship between the acoustic matching layer thickness and the reflector thickness.

From the EP-A1 18 614 an ultrasonic transducer is known using such material as PVDF which can resonant at a frequency less than the free resonance frequency of the piezoelectric material used in the transducer. More specifically it is emphasized in this document that because it is difficult to make a polymer piezoelectrical material very thin, it is difficult to obtain a piezoelectric vibrator which exhibits low free resonant frequency. Therefore it is suggested to provide a transducer made from a material having a thickness of less than 100 μm , which transducer exhibits a resonance frequency less than 10 MHz. Additionally a (or two) layer(s) is (are) provided with either (both) of the acoustic radiation side or (and) the opposite side of the transducer. The additional layer(s) exhibit(s) an acoustic impedance Z larger than $2 \times Z_0$, where Z_0 is the acoustic impedance of the transducer.

As is well known, important factors in assessing an ultrasonic transducer are acoustic radiation efficiency and phase characteristic. The radiation efficiency (referred to in the following as sensitivity S) is defined as the ratio of acoustic energy radiated from the piezoelectric member to acoustic energy propagated to the object. Phase characteristic (referred to in the following as response R) for the transducer having a reflector is determined by the phase difference between a wave reflected at the boundary between the piezoelectric body and the reflector and a wave reflected at the boundary between the reflector and the air which is adjacent to the outer face of the reflector. The phase characteristic influences the resolution of the transducer.

If the thickness of the reflector is so large that the wave reflected at the boundary between the piezoelectric body and the reflector may not interfere with the wave reflected at the boundary between the reflector and the adjacent air, or if the attenuation coefficient of the reflector is large, it is not necessary to consider the phase characteristic in assessing the characteristic of the transducer.

However, it is well known that it is necessary for a transducer to make the reflector thin!

The inventors of the present application found out that, in $\lambda/4$ wave mode, making the reflector thin, may result in a deterioration due to an interference of the above reflected waves because the wave reflected at the boundary between the reflector and the adjacent air is not negligible. In other words, the influence of the last mentioned reflected wave becomes significant in the same extent as the reflector becomes thinner.

SUMMARY OF THE INVENTION

Therefore it is the object of the present invention to provide an ultrasonic transducer of quarter wave length type (shown in Fig. 1) having an excellent phase characteristic.

This object, in accordance with the claim 1, is attained by presenting optimised ranges of thickness and acoustic impedance of the acoustic matching layer when the thickness of the reflector varies.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view showing the construction of an ultrasonic transducer having an acoustic matching layer in accordance with the present invention;

Fig. 2 is a sectional view showing the construction of an ultrasonic transducer devoid of an acoustic matching layer;

Fig. 3 is a graph showing the relationship between the thickness of a reflector of the ultrasonic transducer shown in Fig. 2 and both the sensitivity and response of the ultrasonic transducer;

Fig. 4 is a graph indicating the optimum thickness of an acoustic matching layer with respect to the thickness of a reflector for improved response without a loss in sensitivity in the ultrasonic transducer shown in Fig. 1, wherein use is made of a piezoelectric polymer member according to an embodiment of the present invention;

Fig. 5 is a graph indicating the optimum thickness of an acoustic matching layer with respect to the thickness of a reflector for improved response without a loss in sensitivity in the ultrasonic transducer shown in Fig. 1, wherein use is made of a composite piezoelectric member according to an embodiment of the present invention; and

Figs. 6 and 7 are graphs showing the relationship between the thickness of a reflector and both sensitivity and response for the purpose of making a comparison with the embodiment of Fig. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An ultrasonic transducer according to the present invention has the cross-sectional structure illustrated in Fig. 1. The thicknesses of the acoustic matching layer 4 in examples giving optimum analytical results with respect to the thickness of the reflector 2 are illustrated graphically in Figs. 4 and 5. The materials and acoustic impedances used in each of the examples are illustrated in Table 1. 2. The piezoelectric body 1 may consist of a piezoelectric polymer member or a composite obtained by kneading finely divided powder of a ferro-electric ceramic such as lead titanate or lead zirconate titanate with a polymeric material such as polyvinylidene fluoride, polyvinyl fluoride, nylon, polyacetal or polyacrylonitrile. Figs. 4 and 5 differ in that the piezoelectric body 1 of the former is made of the polymer PVF₂, while that of the latter is made of a composite material. The acoustic matching layer 4 consists of a well-known polymer material such as polyester or polyimide film or a polymer composite. In the graphs of Figs. 4 and 5, the thickness of the acoustic matching layer 4 is plotted on the right side along the vertical axis and the analytic data indicative of the optimum thickness of the acoustic matching layer 4 are indicated by the curve T.

Fig. 4 is for a case where the ultrasonic transducer shown in Fig. 3 is provided with the acoustic matching layer 4. The optimum acoustic impedance of the acoustic matching layer 4 is decided by the acoustic impedance of the piezoelectric body 1 and the acoustic impedance of the load, namely the specimen 5, and in this case is $2.0 \times 10^6 \text{ kg/m}^2 \text{ s}$, as shown in Table 1. The load 5 is water or a living body. The curve T in Fig. 4 indicates examples in which the thickness of the acoustic matching layer 4 is optimum. It will be appreciated from the curve T that the thickness of the acoustic matching layer 4 that improves response R without detracting from sensitivity S differs depending upon the thickness of the reflector 2. It will also be understood from Fig. 4 that the optimum thickness of the acoustic matching layer 4 ranges from $26\lambda_3/120$ to $32\lambda_3/120$ (C-C')

where the thickness of the reflector 2 ranges from $4\lambda_2/120$ to $22\lambda_2/120$ (B-B').

Similarly, the curve T in the graph of Fig. 5 gives the optimum thickness of the acoustic matching layer 4 in an embodiment where a composite piezoelectric member constitutes the piezoelectric body 1. It will also be understood from Fig. 5 that the optimum thickness of the acoustic matching layer 4 ranges from $22\lambda_3/120$ to $28\lambda_3/120$ (G-G') where the thickness of the reflector 2 ranges from $4\lambda_2/120$ to $18\lambda_2/120$ (F-F').

For the purpose of comparison, Fig. 6 shows sensitivity and response for an ultrasonic transducer devoid of the acoustic matching layer 4, and Fig. 7 shows sensitivity and response for an ultrasonic transducer in which the acoustic matching layer 4 has a set thickness of $\lambda_3/4$. Thus, Fig. 6 corresponds to the ultrasonic transducer having the cross-sectional structure of Fig. 2, and Fig. 7 corresponds to the ultrasonic transducer having the cross-sectional structure of Fig. 1. Other conditions are the same as those of Fig. 5, as shown in Table 1 (sheet 1/7).

As will be appreciated from Fig. 6, response R can be improved without detracting from sensitivity S if the thickness of the reflector 2 is selected in the range $8\lambda_2/120 - 30\lambda_2/120$ (D-D'), which is less than $\lambda_2/4$.

Fig. 7 demonstrates that by providing the acoustic matching layer 4 of thickness $\lambda_3/4$, response R is markedly improved while sensitivity S is improved only marginally.

Comparing these with Fig. 5 reveals that a thickness for the acoustic matching layer 4 in the range $22\lambda_3/120 - 28\lambda_3/120$ (G-G') provides sensitivity and response characteristics superior to those of the conventional ultrasonic transducer having the acoustic matching layer 4 of thickness $\lambda_3/4$.

The foregoing facts show that the optimum thickness of the acoustic matching layer 4 becomes less than $\lambda_3/4$ owing to the presence of the reflector 2.

If the thickness of the reflector 2 is made as small as possible, for example zero, the overall ultrasonic transducer shifts to so-called ordinary $\lambda/2$ drive. If the piezoelectric body 1 in this case is subjected to $\lambda/4$ drive, it goes without saying that the optimum thickness of the acoustic matching layer 4 will be $\lambda_3/4 \times 1/2 = \lambda_3/8$. This is evident from Fig. 5, which shows that $\lambda_3/8$ is the optimum thickness of the acoustic matching layer 4 corresponding to a reflector thickness of zero.

ADVANTAGES OF THE INVENTION

According to the present invention as described above, an ultrasonic transducer including an acoustic matching layer and having a reflector the thickness whereof is less than $\lambda_2/4$ has the thickness of its acoustic matching layer selected in a range $(15/120 - 28/120) \times \lambda_3$, depending upon the actual thickness of the reflector. An ultrasonic transducer provided with an acoustic matching layer having this optimum thickness exhibits improved response with no decline in sensitivity. This makes it possible

for the ultrasonic transducer to send and receive ultrasonic signals over a wide band.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

Claims

1. An ultrasonic transducer comprising a piezoelectric body (1) having opposing first and second surfaces, a reflector (2) deposited on the first surface and an acoustic matching layer (4) deposited on the second surface,

said piezoelectric body (1) including a piezoelectric member exhibiting an acoustic impedance Z_T from 2.5×10^6 to 15×10^6 kg/m²s,

said reflector (2) having a thickness of less than $\lambda_2/4$, where λ_2 represents the sonic wavelength internally of said reflector (2) at a frequency which is one half the free resonant frequency of said piezoelectric body (1),

said acoustic matching layer (4) including a material exhibiting an acoustic impedance Z_M of 1.6×10^6 to 4×10^6 kg/m²s, said acoustic matching layer (4) having a thickness of from $\lambda_3/8$ to $28 \lambda_3/120$, becoming thinner as said reflector (2) becomes thinner, where λ_3 represents the sonic wavelength internally of said acoustic matching layer (4) at a frequency which is one half the free resonant frequency of said piezoelectric body (1), and the relation $Z_0 \leq Z_M \leq Z_T$ holding between said Z_M , Z_T and a Z_0 which represents the acoustic impedance of an object (5) under measurement.

2. The ultrasonic transducer according to claim 1, wherein the piezoelectric body (1) consists of a piezoelectric polymer member.

3. The ultrasonic transducer according to claim 1, wherein the piezoelectric body (1) consists of a composite obtained by kneading finely divided powder of a ferro-electric ceramic with a polymeric material.

Patentansprüche

1. Ultraschallwandler mit einem Quarzkörper (1), der gegenüberstehende erste und zweite Flächen aufweist, einem Reflektor (2), der auf der ersten Fläche abgeschieden bzw. ausgebildet ist und einer akustischen Anpassungsschicht (4), die auf der zweiten Fläche abgeschieden bzw. ausgebildet ist,

wobei der Quarzkörper (1) ein piezoelektrisches Element umfaßt, das eine akustische Impedanz Z_T von $2,5 \times 10^6$ bis 15×10^6 kg/m²s aufweist,

wobei der Reflektor (2) eine Dicke von weniger als $\lambda_2/4$ aufweist, wobei λ_2 die Schall-Wellenlänge innerhalb des Reflektors bei einer Fre-

- quenz ist, die der halben freien Resonanzfrequenz des Quarzkörpers (1) entspricht, wobei die akustische Anpassungsschicht (4) ein Material umfaßt, das eine akustische Impedanz Z_M von $1,6 \times 10^6$ bis 4×10^6 kg/m²s aufweist, wobei die akustische Anpassungsschicht (4) eine Dicke von $\lambda_3/8$ bis $28 \lambda_3/120$ aufweist, die bei dünnerem Reflektor (4) dünner ist, wobei λ_3 die Schall-Wellenlänge innerhalb der akustischen Anpassungsschicht bei einer Frequenz ist, die der halben freien Resonanzfrequenz des Quarzkörpers (1) entspricht, und wobei die Beziehung $Z_O \leq Z_M \leq Z_T$ zwischen Z_M , Z_T und einem Z_O gilt, das die akustische Impedanz eines zu messenden Objekts (5) darstellt.
2. Ultraschallwandler nach Anspruch 1, bei dem der Quarzkörper (1) aus einem piezoelektrischen Polymerelement besteht.
3. Ultraschallwandler nach Anspruch 1, bei dem der Quarzkörper (1) aus einem Verbundwerkstoff besteht, der gewonnen wird mittels Durchmischen fein zerteilten Pulvers einer ferro-elektrischen Keramik mit einem polymeren Material.

Revendications

1. Transducteur à ultrason comprenant: un corps piézoélectrique (1) comportant des première et seconde surfaces en regard, un réflecteur (2) déposé sur la première surface et une couche (4) d'adaptation acoustique déposée sur la seconde surface, ledit corps piézoélectrique (1) comprenant un élément piézoélectrique présentant une impédance acoustique Z_T allant de $2,5 \times 10^6$ à 15×10^6 kg/m²s, ledit réflecteur (2) ayant une épaisseur inférieure à $\lambda_2/4$, où λ_2 représente la longueur d'onde sonore à l'intérieur dudit réflecteur (2) à une fréquence qui est égale à la moitié de la fréquence de résonance libre dudit corps piézoélectrique (1), ladite couche (4) d'adaptation acoustique comprenant une substance présentant une impédance acoustique Z_M de $1,6 \times 10^6$ à 4×10^6 kg/m²s, ladite couche (4) d'adaptation acoustique ayant une épaisseur allant de $\lambda_3/8$ à $28 \lambda_3/120$, s'amincissant au fur et à mesure que ledit réflecteur (2) s'amincit, où λ_3 représente la longueur d'onde sonore à l'intérieur de ladite couche (4) d'adaptation acoustique à une fréquence qui est égale à la moitié de la fréquence de résonance libre dudit corps piézoélectrique (1), et la relation $Z_O \leq Z_M \leq Z_T$ étant maintenue entre lesdites valeurs Z_M , Z_T et une valeur Z_O qui représente l'impédance acoustique d'un objet (5) faisant l'objet de la mesure.
2. Transducteur à ultrason selon la revendication 1, dans lequel le corps piézoélectrique (1) est constitué par un élément polymère piézoélectrique.

3. Transducteur à ultrason selon la revendication 1, dans lequel le corps piézoélectrique (1) est constitué par une matière composite obtenue par pétrissage d'une poudre finement divisée d'une céramique ferro-électrique avec une matière polymère.

TABLE 1

	Fig. 3	Fig. 4	Fig. 5	Fig. 6	Fig. 7
	Material/Acoustic Impedence ($\times 10^6 \text{ kg/m}^2 \text{ s}$)				
Piezoelectric Body 1	PVF ₂ /4.0	PVF ₂ /4.0	Composite/10.0	Composite/10.0	Composite/10.0
Reflector 2	Copper plate/44.5	Copper plate/44.5	Copper plate/44.5	Copper plate/44.5	Copper plate/44.5
support member 3	Acrylic/3.0	Acrylic/3.0	Acrylic/3.0	Acrylic/3.0	Acrylic/3.0
Acoustic Layer 4	---	/2.0	/2.5	---	/2.5
Load 5	Water or Living Body/1.5	Water or Living Body/1.5	Water or Living Body/1.5	Water or Living Body/1.5	Water or Living Body/1.5

FIG. 1

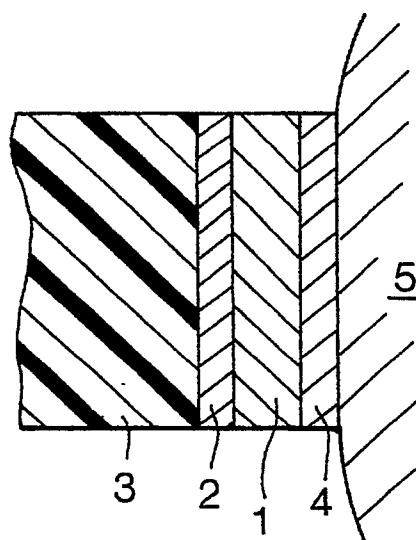


FIG. 2

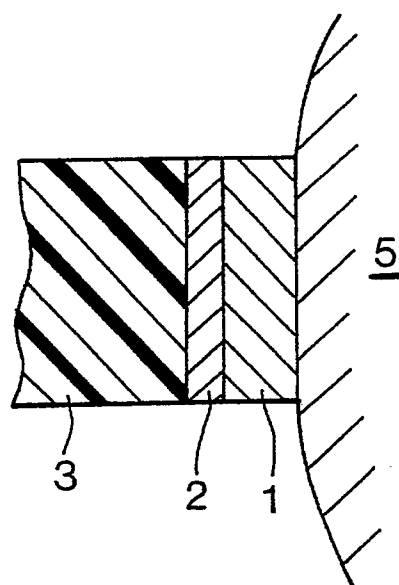


FIG. 3

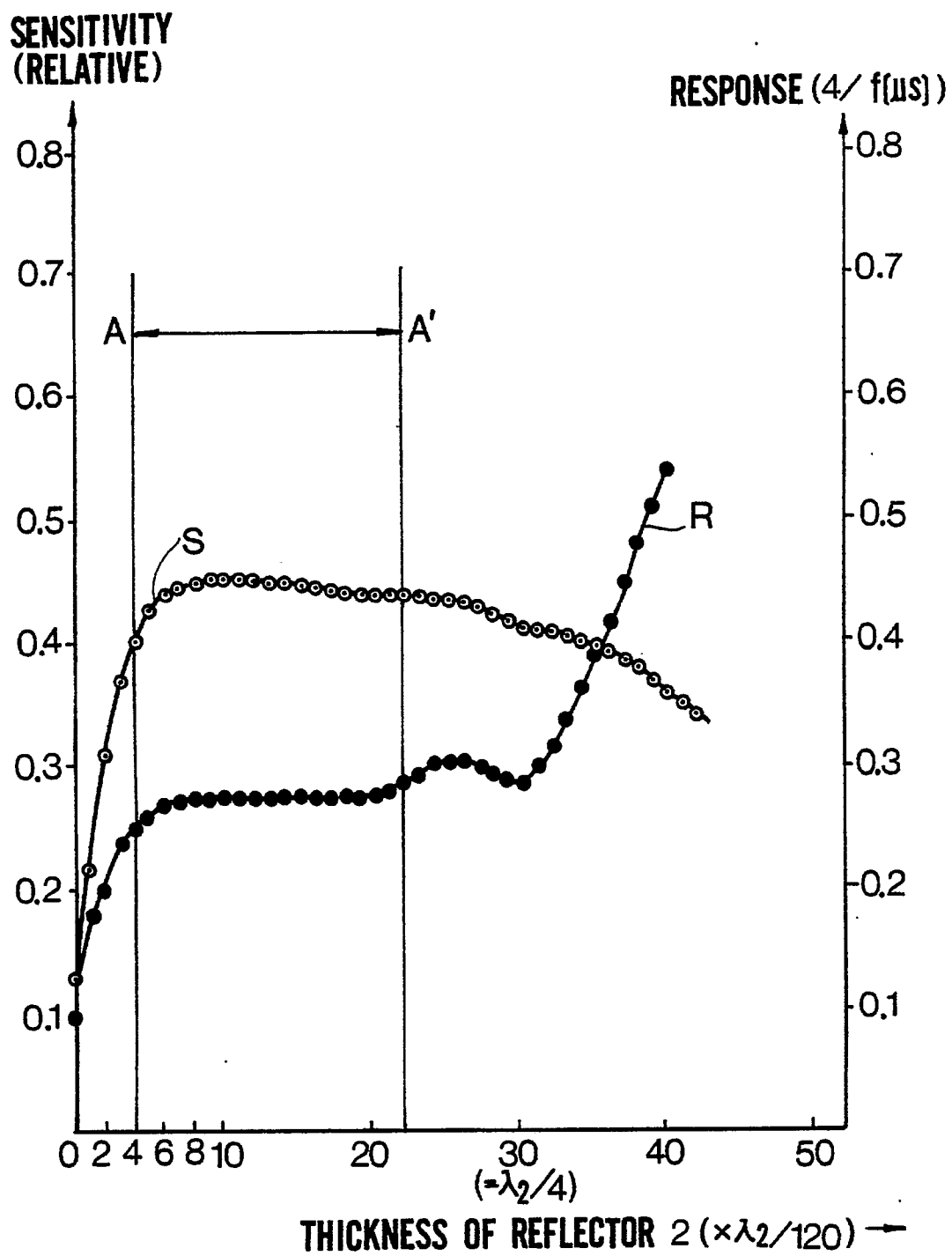


FIG. 4

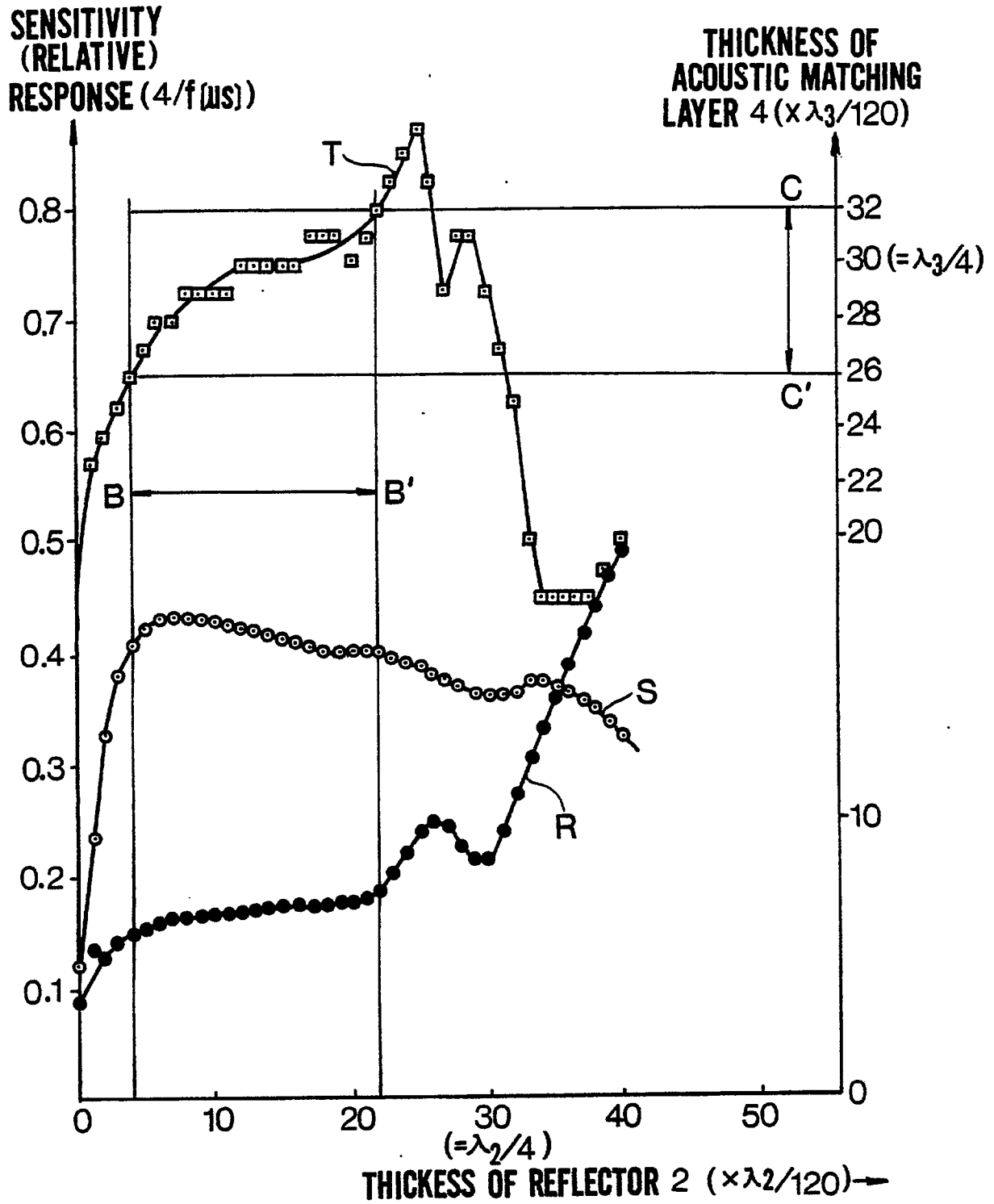


FIG. 5

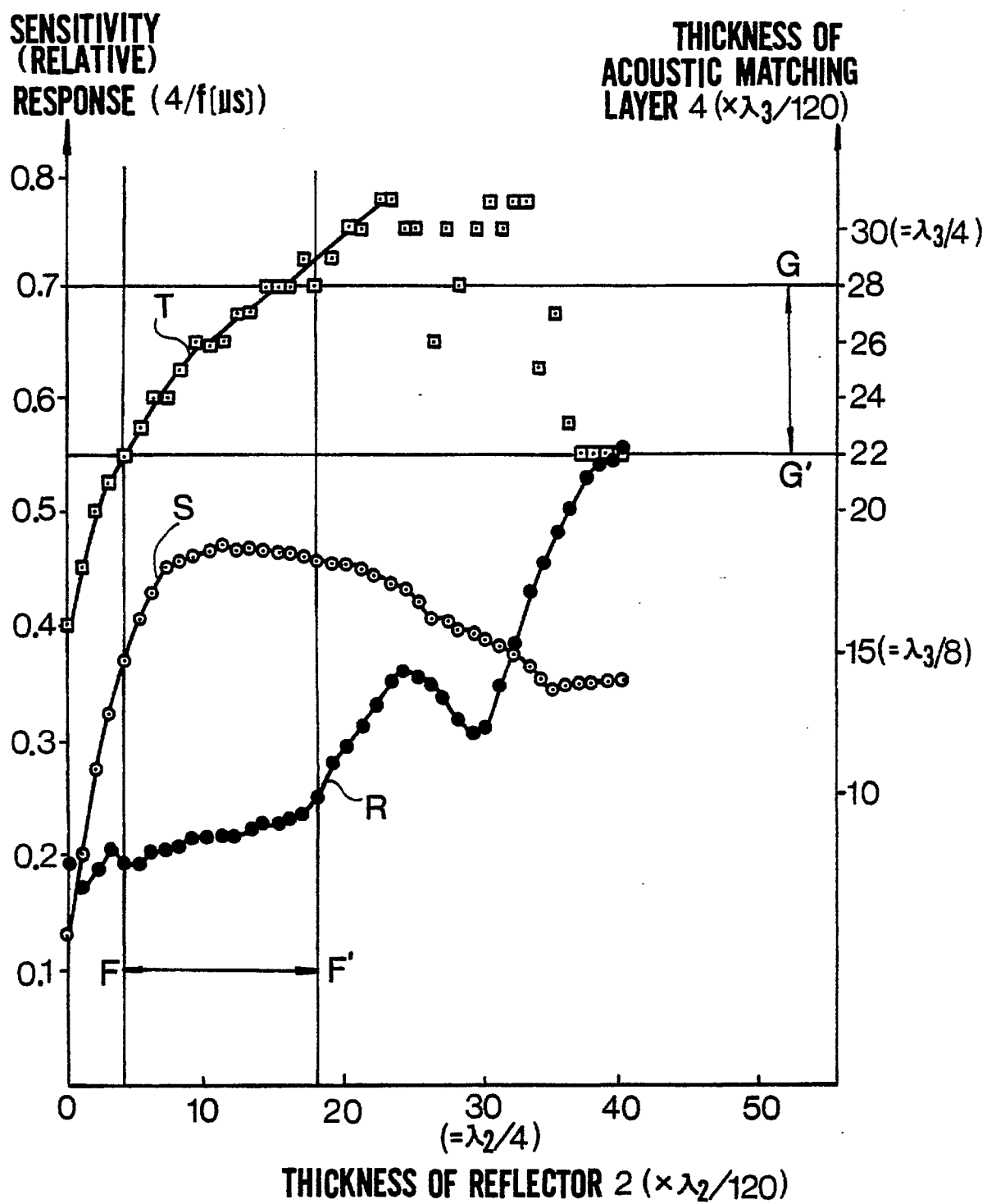


FIG. 6

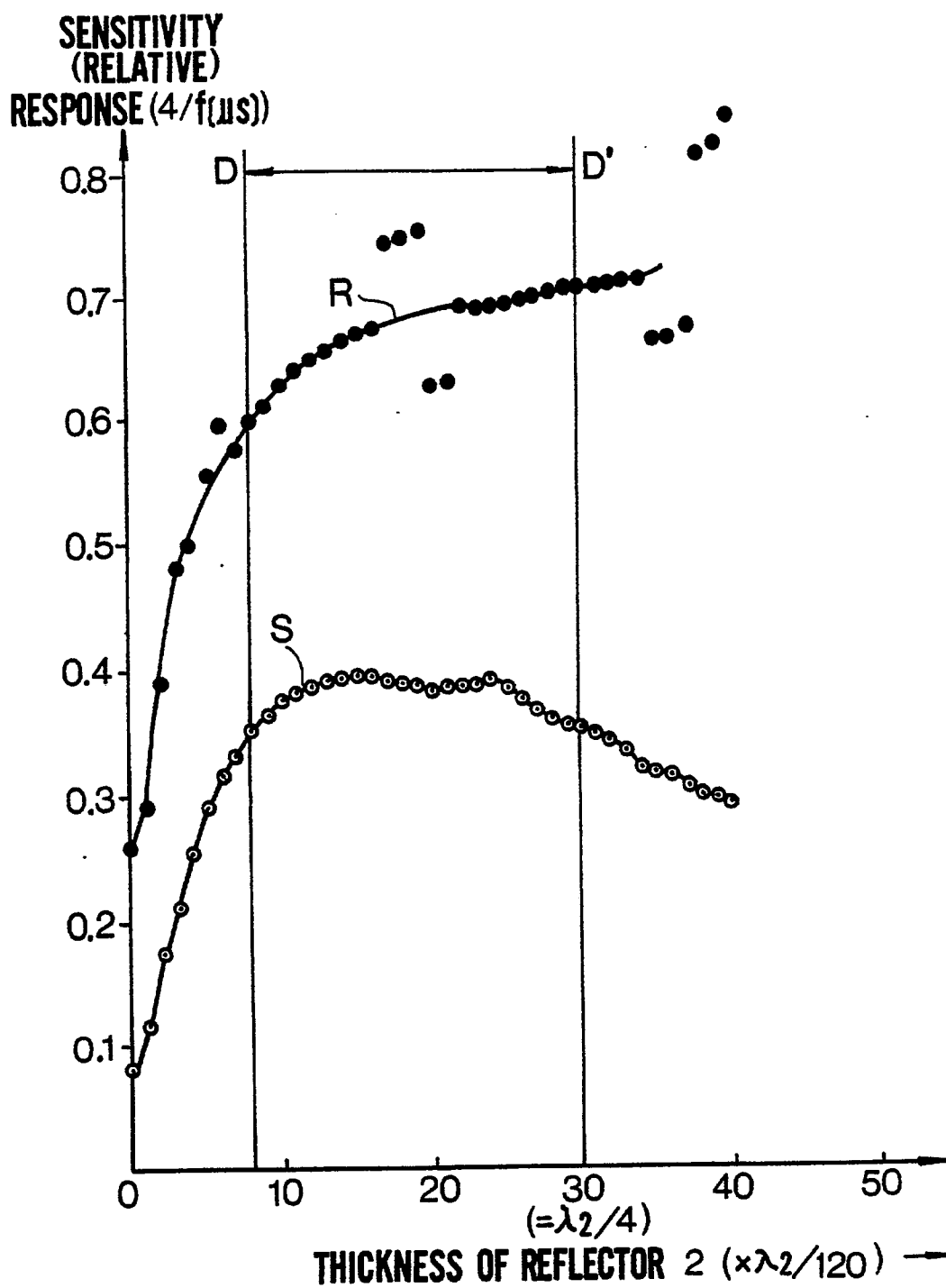


FIG. 7

